of no direct consequence to plants, its importance being purely meteorological, the relative humidity affects them directly, since it so largely determines the amount of transpiration. The monthly mean relative humidity and its minimum, and particularly the average relative humidity with its minimum during periods of different wind direction, are things important to know. In localities with a humid climate and without a distinct hot period, where fogs are frequent, observations upon the latter should, of course, give all the information as to humidity of the air necessary for the purposes of botanical geography.[2]

Precipitation.

The important part which precipitation, especially total precipitation, plays in plant life, needs no discussion. The maximum precipitation for any day during the month and the number of days of precipitation are also important. Since among the latter, however, are included days with only traces of precipitation, the resulting data does not give an idea of the intensity of the precipitation or its frequency. For this reason it will be well to compute the number of days with considerable precipitation in per cent of the total number of days of observation in general, as well as specifically, for winds of different direction.

Snow cover.

Snow cover, of course, also has an important effect upon plant activity. Both the number of days with snow on the ground and the depth of the cover should be recorded. Since the depth of the snow varies with the topography, its depth should be measured at different places. In the valley the snow stakes should be placed, if practical, in an open field and in a wood lot; in the mountains on a level place and on two moderate slopes of the prevailing directions. For each month the average depth of the snow cover should represent only those days when snow was actually on the ground. In order to determine the effect of local topographic conditions, it would be well to note the averages separately for each snow stake. Data on the maximum and minimum of snow cover for each month are also essential, and it is very useful to have the depth of the snow separately for every 10 days (decade). Such detailed information concerning the snow cover is especially instructive at the time of its appearance and disappearance. Since it comes and goes in different years and in different localities at different times, however, this average depth should be given for all 36 decades.

Soil moisture.

In dry regions it is necessary for purposes of botanical geography to have a more detailed knowledge of the humidity of the soil than would ordinarily be indicated by the amount of rainfall and snowfall. In such places periodic and systematic determinations of soil humidity giving due consideration to local topographic and soil conditions are important. Unfortunately, such determinations are not only time consuming, but require a great deal of judgment in the selection of soil samples. The amount of moisture in the soil depends upon the latter's physical properties, its method of cultivation, and so on, and can not be determined accurately at the ordinary weather stations. Therefore it would be of great advantage to students of plant life if such determinations could be made at agricultural and forest experiment stations.[3]

Sunshine.

Light is another important factor in the development of plants. The amount available for plants in a given locality depends upon cloudiness and geographic latitude. For this reason, the average monthly cloudiness, the average cloudiness for winds of different directions, and the number of clear, semicloudy, and cloudy days should be computed. Some simple sunshine record, especially for winds of different directions, is also necessary. The occurrence of days with sunshine should be given in per cent of the total number of observations.

Barometric pressure.

Air pressure has no direct bearing upon plant life, except that its observation often makes it possible to forecast changes of importance to agriculture.

CONCLUSION.

In conclusion, I wish to reiterate what I said at the beginning, namely, that, with the exception of the records of soil humidity and soil temperature, the system of meteorological observations I have outlined can be carried out with the data which are regularly obtained by our weather stations. The change from present practice to the system I have described will entail, therefore, merely a different use of present data rather than a radical change in the plan of collection. The aid to botanical geography which such a change would give would far more than compensate, I think, for any inconvenience or added effort that it might bring about.

TASKS AND PROBLEMS FOR METEOROLOGICAL EXPLORATIONS IN THE ANTARCTIC.

By Prof. Dr. Wilhelm Meinardus, Münster, Westphalia.

[Translated by Cleveland Abbe, jr., from Geographische Zeitschrift, Leipzig, 1914, 20. Jhrg., 1. Hft, p. 18-34.]

No other region on the earth has witnessed during the past decade, such advances in our knowledge of its meteorological conditions as has that within the higher southern latitudes. As Hann was closing the second edition of his Handbook of Climatology in 1897 he was practically limited in material for the climate of the Antarctic Zone, to that collected in its seas 50 to 60 years previously by Sir James Ross. There was no

[2] The adoption by all weather stations and observers of a standard evaporometer would, in a large measure, solve the question of humidity and wind-movement records and would furnish data directly usable by the plant bi ologists.

[3] Here again the adoption of a standard apparatus seems the only means of obtaining desirable data for large areas and for different regions. The great difference in soils in different localities and the great difficulty in any one locality of obtaining consecutive samples of soil which are physically alike, makes it necessary that any apparatus designed for consistent soil-moisture determinations shall involve the plan of always measuring the same body of soil. The electrical resistance apparatus is good in this respect, but, unfortunately, is not always reliable from a mechanical standpoint. A comparatively simple piece of equipment has been suggested by C. G. Bates of the Fremont Forest experiment station. This is a porous cup which would contain the sample of soil whose moisture was to be determined periodically. This porous cup would fit closely inside a second similar cup, which would, in turn, be located at the bottom of a brass tube at any desired depth below the surface of the ground. To the soil cup would be attached a cord or rod which would extend up through the brass tube. At the top of the tube would be a firmly built platform, on which could be placed a sufficiently delicate balance for weighing the soil cup. When weighing was desired the cup would be raised sufficiently to clear the exterior cup attached to the beam of the balance and then replaced. The contents of the cup might be a sample of the local soil, a standard sand or soil of certain physical and mechanical properties, or a standard salt with a slight avidity for water. Under either plan the moisture of the contents (by absorption or expulsion through the porous walls) would always bear a certain relation to the moisture of the surrounding soil.

information available for the Antarctic mainland, whose areal extent is one and a half times that of Europe. Indeed, but 15 years ago Antarctica had not yet one single meteorological station, so that Hann closed his work with the words: "Eine, oder noch besser mehrere Überwinterungen in hohen südlichen Breiten würden einige der wichtigsten und interessantesten Probleme der wissenschaftlichen Klimatologie zu lösen imstande sein. Die Kenntnis der Wintertemperatur im Polargebiet einer Wasserhemisphäre ist gegenwärtig das dringendste Erfordernis unserer Wissenschaft."

The desire of our greatest climatologist that there might be one or more winter-long expeditions to the Antarctic, there voiced, was soon to be fulfilled. The first wintering was in 1898–99 in the seas west of Graham Land, by the Belgian expedition under De Gerlache in the *Belgica*. It was not granted this expedition to establish a land station; caught in the floes the ship was compelled to drift along an unknown and unseen stretch of the Antarctic coast. Borchgrevink's expedition to Ross Sea was the first to establish and maintain a land station. It was located at Cape Adare for almost a year in 1899–1900. These two expeditions were the advance guard of a new epoch in Antarctic exploration which began with the new century. It is still fresh in the memory and its latest victories, the extension of our horizon to the South Pole itself by Amundsen and Scott, still thrill us. I may then pass over the various stages of this latest activity in exploration. Germans, French, English, Scotch, Norwegians, Swedes, Argentinians, Australians, all have had a part so that this field of exploration is more truly international in character than any other on the globe. Here the fame of success beckons not merely to the ambitious explorer, but more alluringly to the investigator who would sink himself in study of the peculiar nature of a lonely, sea-surrounded icy continent never yet even brushed by any form of human culture.

It is my purpose to communicate some of the meteorological results [1] which may be based upon the observational material collected by the Antarctic expeditions of the past decennium, as well as to review the still unsolved problems which must spur us onward to further exploration in Antarctica.

CHARACTER OF PREVIOUS METEOROLOGICAL OBSERVATIONS.

We may begin by considering the character of previous collections of meteorological observations in our field and their evaluation. (See the map, fig. 1.)

Observations have been made at mainland stations, on sled journeys, on drifting floes, and recently also by means of kites and balloons.

Fixed land stations.—In studying the atmosphere, stations at fixed points are of the most value, because the external conditions of the surroundings remain the same. Such observations, when continued through one or more years, can be used to determine seasonal contrasts and to ascertain averages that apply to the surroundings of the station. Such stations have the further advantage that they can be revisited by other expeditions, so that one may secure comparable data for various years.

So far eight localities within the true south polar region have been occupied as meteorological stations of some duration and one of them, Adélie Land, is still maintained. These stations were located as shown in Table 1 and the map, figure 1.

TABLE 1.—*Meteorological stations in Antarctica occupied for one or more years.*

Station.	Nationality.	Lat.	Long.	Periods.
West Antarctica.				
Laurie Island	Scotch / Argentine	60° 44′ S.	44° 39′ W.	1903–1914 (?).
Snow Hill	Swiss	64° 22′ S.	57° 00′ W.	1902–3.
Port Charcot	French	65° 04′ S.	63° 42′ W.	1904–5.
Petermann Island	...do	65° 10′ S.	63° 54′ W.	1909.
East Antarctica.				
Cape Adare	Norwegian	71° 18′ S.	170° 09′ E.	1899–1900.
Gauss Station	German	66° 02′ S.	89° 38′ E.	1902–3.
MacMurdo Sound	English	77° 45′ S.	160° 30′ E.	1902–1904, 1908–9, 1911–1913.
Framheim	Norwegian	78° 38′ S.	164° 30′ W.	1912–13.
Adélie Land	Australian	66° 30′ S.	140° 00′ E.	1912–1914 (?).

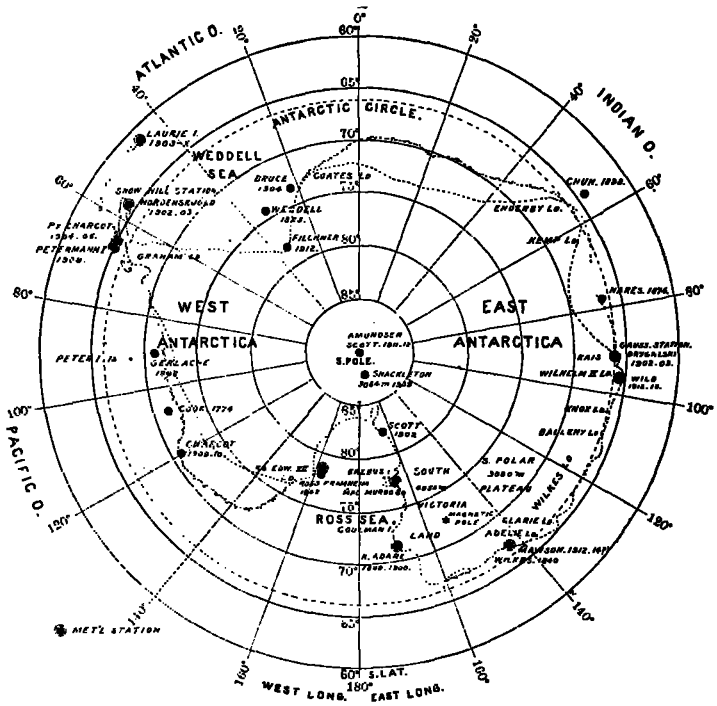

FIG. 1.—Location of meteorological stations within the south polar regions.

Some of the stations listed have had branch stations in their vicinities for longer or shorter periods, e. g., on the Gaussberg, on Mount Erebus, etc.

Thus it appears that so far the fringe only of the Antarctic continent has been occupied by fixed stations, of which the southernmost is Amundsen's "Framheim" in lat. 78° 38′ S., or about 1,300 km. from the South Pole; Spitzbergen has a corresponding location on the Northern Hemisphere.

Sled journeys.—Another kind of material is secured on the polar sled journeys, which usually have one of these fixed stations as their starting point. In the nature of things these observations can be but scattered samples of the atmospheric conditions along their routes. Because of the almost continuous change of place the individual observations can not be summarized and given general application. In general, all the elements observed vary with each locality, so that in utilizing meteorological observations made on sled journeys one must always bear in mind that the weather then encountered may depart more or less widely from the average conditions or climate

[1] See also Hann's exposition in his Handbuch d. Klimatologie, 3d ed. Stuttgart, 1911, v. 3, p. 677–699.—W. M.

of the region. This fact has not always been considered, and the resulting hasty conclusions may readily be undermined by later observations. Furthermore, sled journeys are usually undertaken during the polar daylight, so their observational material is applicable only to a certain season of the year. However, sled journeys can furnish information of general value concerning the climate of the regions traversed by recording the depth of the snow and the ice covers, the orientation of the snow dunes, phenomena of melting, and such features. In this way they are always very important aids to our knowledge in case other means fail.

Sled journeys of major significance have been limited to the eastern portion of Antarctica. The trips in Victoria Land made by the English expeditions seeking the magnetic South Pole are specially noteworthy We would not omit to mention the poleward trips associated with the names of Scott, Shackleton, and Amundsen.

Floe-drift journeys.—A third class of observations result from expeditions compelled to drift in the ice floes. The usefulness of such material is intermediate between that of the fixed stations and that from sled journeys. The floe-drift and the fixed station agree in that the surroundings do not materially change during the period of occupation, for the observation is always at the ship and the surroundings are always snow and ice. On the other hand the gradual shifting as the floe moves is similar to that of the changing sledding camps, although the former is very slow, while in the latter case rapid changes are specially emphasized. Accordingly the floe-drift observations acquire more or less significance as the duration and direction of the drift journey varies.

The essentially floe-drift expeditions to the Antarctic include the *Belgica* expedition west of Graham Land in 1898–99, the *Scotia* expedition of 1903–1904, and the German Antarctic expedition of 1912 in Weddell Sea. Besides these a large number of other expeditions have been compelled to drift sometimes for months, as was the lot of the German South Polar Expedition from the beginning of February to the beginning of April, 1903, after it had left its winter quarters.

Kite and balloon observations.—Finally come the endeavors to learn the nature of the higher atmospheric strata by means of kites and balloons. Here also the results are mostly in the nature of isolated samples of the meteorologic conditions; and again it must be borne in mind that the observations are determined by the momentary weather conditions, so that they do not suffice for general averages unless they can be repeated daily at the same locality. Great care must be used in basing general conclusions upon such material. However, this in no way detracts from these upper-air observations since they are of the greatest significance to studies of the momentary conditions and of weather sequence.

Certainly one of the greatest triumphs of the German South Pole Expedition was Dr. Barkow's [2] successful carrying out of 255 ascensions on 209 days during the floe-drift journey in Weddell Sea. A preliminary computation indicates that the highest balloon sounding reached an altitude of 17,200 meters [56,430 feet, or 10.7 miles]. These series of flights furnish the first noteworthy data bearing on the upper-air conditions over the Antarctic regions, and we may well look forward expectantly to the general conclusions which this first pioneer work shall warrant. Under other circumstances one must rely upon cloud observations for information bearing upon upper-air conditions, and numerous contributions of this kind have already been made.

[2] *Barkow, E.* Vorläufiger Bericht über die meteorologischen Beobachtungen auf der Deutschen Antarktischen Expedition. Veröffentl. Preuss. meteorol. Institut. Berlin, 1913.

NEEDS IN FUTURE EXPLORATION.

In general, it is clear from the foregoing that future expeditions to the Antarctic will best further the study of its climatology if they establish long-lived fixed stations which shall be located as far inland as possible. It seems that the establishment of subsidiary stations is also very useful, since they aid in determining the extent of local conditions. Of course such expeditions will also arrange for simultaneous kite and balloon flights. We may well hope that the modern and future development of aeronautics will also contribute to the exploration of the South Polar regions.

METEOROLOGICAL CONDITIONS AND PROBLEMS OF ANTARCTICA.

Previous observations on the atmospheric conditions of the Antarctic continent have revealed many unexpected problems. Foremost among these is the element "Temperature" which directly or indirectly sets its stamp upon the country.

Summer temperature.

The low summer temperature is the most important characteristic of the South Polar temperature distribution. The average temperature of the warmest month, December or January, is below 0° C. almost everywhere along the borders of the Antarctic mainland. The only exception to this is the west coast of Graham Land, where the French expedition found a mean January temperature of 1° C. in latitude 65° S.; and this is offset by a mean January temperature of only −0.9° C., found by the Swedish expedition on the east coast of the same land in latitude 64° 30′ S. If one computes the average January temperatures for the latitude circles it appears that the isotherm for 0° C. almost coincides with the Antarctic Circle (lat. 66° 30′ S.). The region bound by this curve has an areal extent of 21,000,000 square kilometers, more than double the extent of Europe [or of Australia, and about half that of the Americas]. In spite of its favorable summer insolation [perihelion summer], this extensive region stands under the sign of Jack Frost.

The North Polar regions have far more favorable conditions. Mohn's discussion of the observations by Nansen's expedition in the *Fram* indicates a July temperature below 0° C. prevailing over a limited area (800,000 square kilometers), within the latitude of 85° N. Thus in the warmest month the isotherm of 0° lies but 450 kilometers from the pole in the north, while in the south it has an average distance of 2,600 kilometers from the corresponding point.

But the summer temperatures of the southern polar regions are not merely close to freezing; the farther poleward one goes the farther sinks the summer temperature below 0° C., in spite of the more favorable insolation conditions. So that Amundsen found the average temperature of the warmest month (December) at Framheim (lat. 78° 38′ S., alt. close to sea level) to be but −6.2°. This is a fact difficult of explanation, since the insolation at this high southern latitude continues uninterruptedly day and night through the summer months except as it may be decreased by the rather slight cloudiness. The sled journeys toward the South Pole also show altogether unusual low temperatures for the summer season in which they were made. A midsummer temperature of −50° C. (−58° F.) is not to be readily explained even though the district about the South Pole itself does lie at an altitude of over 3,000 meters [i. e., over 9,840 feet].

One of the principal problems for future expeditions will be to find the explanation of this low summer temperature at high southern latitudes. It may be expected that future upper-air investigations will aid in the solution.

Winter temperature.

Another heretofore unexplained phenomenon is the uniformity of the winter temperature during April to September. The feature is most pronounced in East Antarctica at the English station on MacMurdo Sound. There the monthly temperatures remain between 24° and 27° C. from April to September. The annual temperature curve seems to be flattened, quite in contrast to its course in the Northern Hemisphere where the temperature sinks rapidly until midwinter when it immediately begins to rise again. Why is there no pronounced Antarctic winter month whose low temperatures distinguish it sharply from its neighboring adjacent months?

Local temperature contrasts.

The local differences in temperature distribution over the margin of Antarctica will not be discussed here. It must suffice to say that the east and west sides of Graham Land show important differences, the west side being warmer than the east side. This feature is primarily referable to the different wind conditions, and it may well be compared with the differences prevailing between the west and east coasts of Greenland.

There is a surprising and unexplained difference between the observations at Framheim (Amundsen) and at MacMurdo Sound (English). Although both localities are in almost the same latitude, are at sea level, and similarly located at the edge of the Ice Barrier, yet there is a difference of not less than 7.5° C. between the two annual means, Framheim being colder than MacMurdo Sound. Further, Framheim shows the lowest mean annual temperature (−25.2° C., −13.4° F., in lat. 78° 38′ S.) so far observed anywhere on the globe. The lowest average temperature observed during the *Fram's* drift in the Arctic Ocean was −20.5° C. (−4.9° F.) for 1895 and an average latitude of 85° N. Some years ago the author computed the average annual temperature for the South Pole and found −25° C., a result which will probably be regarded as somewhat too high.

Does the cold pole of the Southern Hemisphere coincide with the south geographic pole? This problem awaits solution. Previous observations make it probable that the cold pole is located somewhat eccentrically, being shoved over toward the Indian Ocean, for the antarctic shores of the South Atlantic and South Indian Oceans are somewhat colder than those of the South Pacific.

Pressure and winds.

The more recent investigations show the sea-level pressures and winds of West Antarctica are about what theory would predict. Wind conditions indicate that a trough or furrow of low pressure surrounds the south polar regions in latitudes 60° to 70° S., and an increasing pressure from those latitudes poleward. (See fig. 2.) The low-pressure trough or furrow, appropriately designated the subantarctic circumpolar barometric trough or furrow, is thus seen to act as an important wind divide.

Formerly it was believed that the east winds south of the trough were blowing from the high-pressure area supposed to cover the antarctic lands. These east winds were supposed to be of antarctic origin and to have the dry, cold character of winter land winds such as might blow from an area of continental high pressure. Observations in these regions have not supported this view. On the contrary the east winds met with in the marginal region of the westerly winds are not dry and cold but moist, warm, and snow-producing. Drygalski's German South Polar Expedition established this point most clearly. As the *Gauss* sailed southward from Kerguelen in February, 1902, she was for a while in the zone of westerly winds, but after crossing latitude 64° S. entered the region of easterly winds where she remained for over a year. During this time the prevailing wind was easterly and whenever these east winds showed marked increase in force the weather became warm and moist with copious snowfall. To be sure the higher temperature of the east winds might be explained by assuming they are of southern origin and a föhn-like character; their higher humidity contradicted this view. The heavy precipitation characterizing these east winds is yet more discordant with the föhn theory.

If these easterly winds of the *Gauss* station are regarded as cyclonic in nature their warm, moist character is readily and adequately explained. In this case their origin must lie to the north, that is in the region of the southern Indian Ocean. This view also harmonizes with the observed subantarctic trough of low pressure which serves as the path of the depressions that march from west to east about the South Polar regions.

Of course in the barometric depressions of the Southern Hemisphere the air circulation is spirally clockwise. (See fig. 3.) Accordingly the east winds on the south side of these depressions must have a northern origin. They are coming from warmer latitudes and from the ocean, and their higher temperature and humidity is a natural consequence. The winter station of the *Gauss* was particularly favorable for the clear development of these features. No mountains, peninsulas, or other topographic features could disturb the air currents. The even coast of Kaiser Wilhelm II Land stretches from west to east and the *Gauss* station was located 90 km. north of the coast.

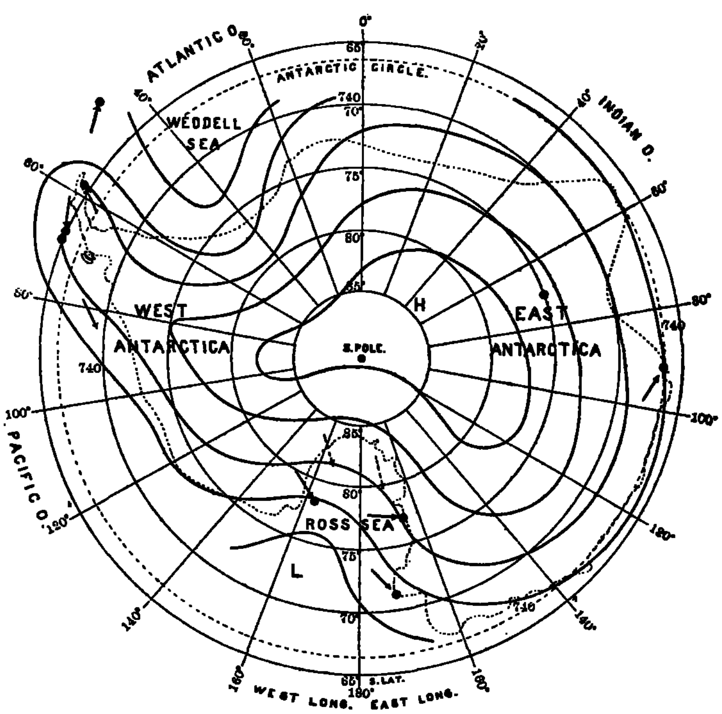

FIG. 2.—Sketch of the course of the isobars at sea level within the south polar regions. The isobars are intentionally unnumbered except the curve for 740 mm., whose position can be plotted with some certainty by aid of past observations. The drawing is planned to present only the *probable form* of the isobars, considering the observed sea-level winds. H, high pressure; L, low pressure; arrows, average wind direction.

Most of the other Antarctic stations have had similar experiences with the east winds. Thus the warmest winds were from the northeast and north at the Swedish station on the east side of Graham Land, and at the French stations on the west side of the same. The *Scotia* had cyclonal northeast winds at the east side of Weddell Sea. In and about Ross Sea the conditions are more complicated. Here the mountains of Victoria Land, modify the direction and the character of the air currents which can not be so simply described. It must be assumed that the barometric trough which forms the divide between the easterly and the westerly winds, bends southward in the region of Ross Sea or that there is here a tendency to develop an independent pressure minimum. It then becomes clear (see fig. 2) why the southeast winds were the warmer at the English stations in the southern portion of Ross Sea.

The distribution of pressure and winds over Weddell Sea show similar modifications. Mecking and Mossmann find this region dominated by low pressure especially during the winter, so that southwest winds prevail along the west side and northeast winds prevail along the east side. The floe-drift observations on the *Deutschland* in 1912 confirmed these assumptions.

The modern explorations have thus necessitated some modifications of the simple scheme of pressure and wind distribution to bring it into accord with the continental outline of Antarctica. The most important fact emerging from these observations is that the easterly winds of the continental margin must be regarded as members of the circulation about centers of low pressure passing north of Antarctica. The east winds to the south of the sub-Antarctic circumpolar barometric trough are the necessary corollaries of the west winds to the north. A comparison of the weather observed at Kerguelen and at *Gauss* station shows this.

The international meteorological coöperation of 1901–1904, originated by the German Antarctic expedition, was able to follow the course of the weather in high southern latitudes much more accurately than the expedition could have done alone. Mecking and Meinardus have drawn up synoptic weather maps for the Southern Hemisphere south of latitude 30°, whereon one may trace the paths of the highs and lows across the seas surrounding Antarctica. The study has not yet been completed, but it is already possible to state that these charts confirm the view which regards the marginal east winds of Antarctica as elements of cyclonal systems.

The mechanics of these depressions appear to be much more complicated than we have heretofore been ready to assume. It had been thought that in the broad zone of water uniting the oceans on the south the development and movement of the pressure system would show simpler features than in the northern zone of our latitudes, where continents and seas alternate. But in the south, also, the relations are complex; lows and highs undergo varying modifications, and their movements do not show that uniformity that the expedition of 1901 expected to find when it sailed for the south.

A question still unanswered is as to the great constancy of the east winds. At the winter quarters of the *Gauss* these winds blew with a constancy almost equaling that of the trades; rarely were they interrupted by calms or by westerly winds. There is undoubtedly some relation between the simple character of the coast line and this constancy of the east winds, but their dependence upon the advancing depressions on the north leads us to expect a lower degree of constancy in these winds.

We also need further explanation of the unusual frequency of the extremely stormy, cold southwest wind recorded at the Snow Hill station. As was stated above, this wind indicates a region of low pressure over Weddell Sea, but it is striking that the wind is dry and cold and therefore can not be considered as of truly cyclonal character. We shall return to the consideration of this wind.

Precipitation.

Certainly the chief characteristic of the Antarctic precipitation is that it almost always takes the form of snow. Rainfalls belong to the greatest rarities. This explains why so little has been known as to the amount of precipitation for, as is well known, there are great difficulties in the way of the measurement of snowfall and particularly in the polar regions which are covered with loose snow.

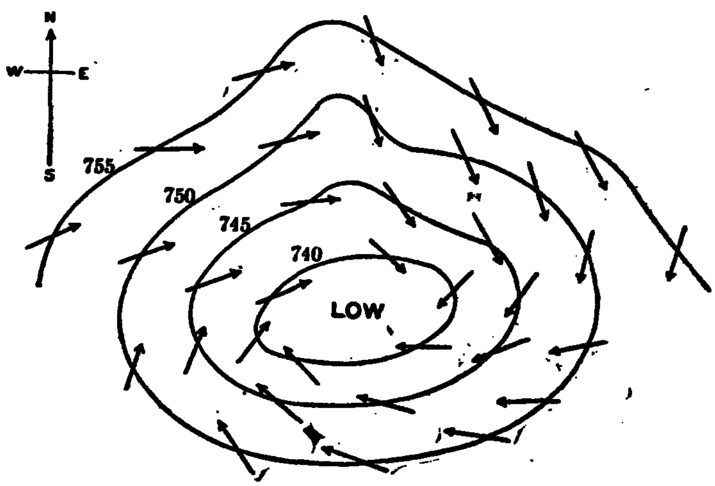

FIG. 3.—Circulation at sea level of a cyclone in the Southern Hemisphere.

Previously fallen snow is whirled up by the wind, and even during fine, dry weather drifting snow can fill the gages with falls that have already been measured. Even when actual new snow is falling it is blown from the gage and but a small part is measured. There are, indeed, devices for reducing such losses at the gage but they are not adequate to remove the source of error. In general it is safer to use staff gages set up at well-selected points so that uniform records may be secured for driftings of various intensities. The readings of such staff gages certainly yield more reliable results than those from the simple snow measurer, which is no other than a rain gage.

For these reasons the previous measurements in the Antarctic are hardly sufficient to give an accurate idea of its precipitation. Therefore it may be stated that one of the most urgent needs is a device which is adapted to securing records, even during an Antarctic snowstorm, that will permit a somewhat reliable estimate of the precipitation.

The available measurements will scarcely bear discussing; however, the following may be mentioned: When the east winds on the margins of Antarctica have a cyclonal character—i. e., are bringing moisture from northern latitudes—then it is very probable that they will bring specially heavy precipitation. Here we may point the analogous expectation in the North Temperate Zone that east winds on the poleward side of barometric depressions will bring unusually heavy precipitation. In Germany the heaviest snowfalls usually occur with northeast and east winds accompanying a Low over the Mediterranean to the south and a High over Scandinavia or

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northwestern Europe. The process is as follows: On the east side of a depression the southerly winds bring moisture northward from the warm Mediterranean region and transfer it to the north side of the depression. Here, at the boundary between the cyclonal and anticyclonal areas, cooling causes precipitation which generally takes the form of snow. Now does the southerly depression move in general toward western Russia following storm path *Vb* [*see* Bebber, Lehrbuch der Meteorologie, *or* Milham, Meteorology, p. 301, fig. 124, *or* Bartholomew's Physical Atlas, v. 3, pl. 28], then there develops a belt of heavy precipitation parallel with the direction of the storm's path. The great snowfalls of March 15–17, 1894, over northeastern Germany and of March 9–12, 1901, associated with the extensive dust fall over northwestern Germany, are proofs of this process. It no doubt occurs also on the east coasts of Greenland and of North America.

It is probable that similar conditions arise on the southern side of depressions moving along the margin of Antarctica. In this case northerly winds bring in moisture from the ocean to the southern side of the Low, and on the boundary between the Low and the High the moisture separates out in the form of snow. The snow measurements at the *Gauss* station indicate, in my opinion, that the precipitation there exceeds 800 mm. per year, a very heavy fall for the low temperature prevailing there. On the western side of Graham Land, also, with prevailing northeast winds there occurs heavy precipitation under similar conditions, the measured annual fall at Port Charcot amounting to almost 400 mm. In this case the northeast winds come from the perennially open and warm waters of Drake Straits, and there must be a correspondingly great transfer of moisture toward Antarctica.

On the other hand, the precipitation is evidently much smaller in Weddell Sea and its western boundary. It is true that the observations at Snow Hill station are not usable, for the reasons already stated; nevertheless the precipitation can not be very large for prevailing southwest winds were generally dry in spite of the frequent schneetreiben which accompany them. The *Deutschland* also found very light precipitation during its floe-drift in Weddell Sea, only 98 mm. in amount. This measurement was by means of a rain gage, and though it may be quite inaccurate still, as Barkow says, this figure gives some reason for believing that the district is one of small precipitation.

On the whole, then I would regard it as very probable that those portions of the margin of Antarctica which are fanned by cyclonal easterly winds are regions of heavy precipitation. On the other hand those portions which, like western Weddell Sea and Ross Sea, are exposed to southerly winds are regions of light precipitation. Further observations are needed before more detailed conclusions may be drawn. Heretofore we have had but a general knowledge of the annual period of the precipitation, the observations indicating that the summer precipitation is heavier than that of winter.

Source of the inland ice.

Such investigations into the distribution of the Antarctic precipitation are, of course, of the greatest importance in one of the cardinal problems of the Antarctic: What are the meteorological conditions which supply and maintain Antarctica's continental ice sheet, the "Inland Ice"? That cover of ice and snow forms the most prominent feature of Antarctica, and it exerts the most far-reaching influence upon the climatological phenomena of all its surroundings. I have also studied the problem of the source of supply for the inland ice when working up the results of the German South Polar Expedition. Permit me to briefly present my views thereon.

It is a well-established fact that there is a steady flow of ice from the unknown interior of Antarctica. This ice sheet overflows the margin of Antarctica and presents an almost unbroken line where it surrenders to the sea in the form of icebergs. The origin of this ice can not lie along the continental margin only, it must also be located farther poleward for there can be no doubt that the interior mainland also lies snow buried as does its margin. Sled journeys into the interior and to the Pole prove that even in these central portions of the Antarctic mainland the determining elements of the landscape are snow and ice: nowhere appeared extensive snow-free areas.

Now if the interior of Antarctica is covered with snow and ice and there is a discharge of the same to the marginal oceans, it follows that over Antarctica as a whole the precipitation exceeds the evaporation. Marginal ice discharge could occur only in such a region. It further follows that the excess of precipitation over evaporation must be furnished by air currents moving toward the interior of Antarctica. The hydro-economics of Antarctica must be somewhat as follows: The marginally discharging ice is exporting water from the south polar regions; this water loss must be compensated by an excess of precipitation over evaporation; and the excess precipitation must be made possible by a corresponding supply of water vapor carried by winds into the interior.

If the water imported annually be designated by D_e, the exported water vapor by D_a, the precipitation by N, the Antarctic evaporation by V, and the exported ice by E, then under constant climatic conditions the annual state of affairs must be expressed by the equation:

$$D_e - D_a = N - V = E.$$

How can this equation be satisfied? This question can only be answered by considering the air currents and the distribution of pressure at levels higher than the earth's surface.

Antarctic pressures.

The general view is that the whole south polar region is dominated by a region of high pressure. This view is based upon the existence of easterly winds on the margin of Antarctica and the observed southward increase of pressure. We have already seen that the margin of Antarctica is not under anticyclonal but cyclonal pressure conditions. If there is an Antarctic anticyclone it can exist only in the inner portion of Antarctica (see fig. 2); and its existence there is a difficulty in the way of explaining the necessarily assumed interior snow cover. For air flows toward an anticyclone in its upper layers, then descends as relatively dry air, and below flows outward in all directions. Under such circumstances, unfortunately for the theory, precipitation cannot form in sufficient quantities to outbalance the evaporation as expressed in the above equation. On the other hand, evaporation is greater than precipitation in anticyclonal areas; the air descending from greater heights is dynamically heated, becomes relatively very dry, and as it flows outward takes up moisture from the earth's surface and removes it from the region of the anticyclone. In our case this known mechanism of the anticyclone would necessarily cause a drying-out and removal of snow cover in the interior of the south polar regions.

This consideration induces me to revise the theory of an Antarctic anticyclone. A certain line of reasoning, which I shall not repeat here, shows me that the Antarctic continent must have a very high mean elevation, as much as 2,000±200 m. above sea level. Herein lies the key to the phenomenon of Antarctica as a possible and even actual source of supply of the inland ice. For now one may draw the following conclusions: The Antarctic anticyclone, so much discussed in the past, is a pressure distribution peculiar to the lower atmospheric strata only, appearing with distinctness only in the sea-level pressure distribution. On the other hand the low Antarctic temperature must produce such a rapid vertical decrease in pressure that above a certain level the Antarctic pressure must be lower and not higher than that of surrounding regions. Thus the sea-level anticyclone must be overlain by a cyclone, the so-called "polar whirl" in the general circulation of the globe. (See the characteristic isobars at 4,000 m. in fig. 4.)

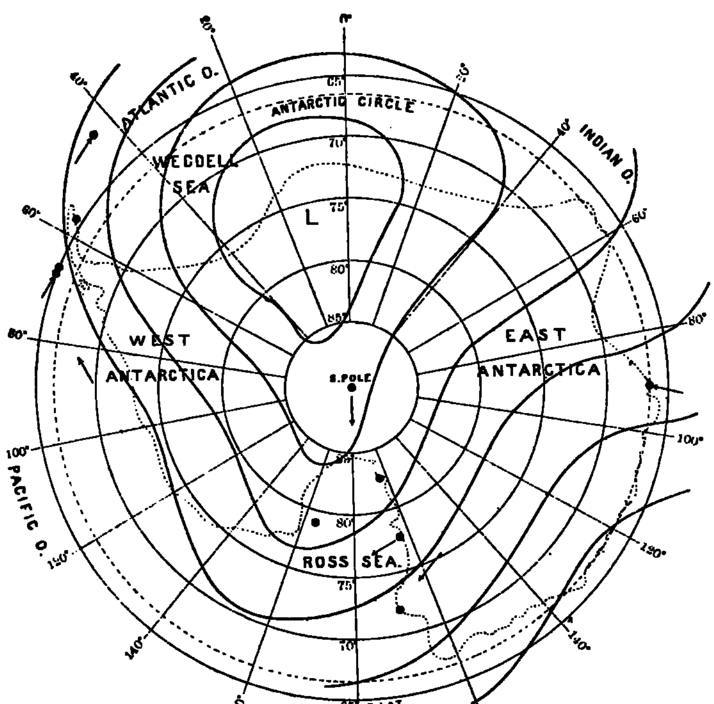

FIG. 4.—Sketch of the isobars at the 4,000-m. level within the south polar region. Arrows show average direction of the upper clouds and the prevailing winds on the plateau.

By making certain assumptions regarding the distribution of temperature and pressure one may calculate the upper limit of the anticyclone. From this it appears that this limit is less than 2,000 m. during the greater portion of the year, or that it lies below the mean level of the south polar continent. Accordingly there must be extensive areas of Antarctica that always lie higher than the level of the anticyclone and reach up into the levels of the polar cyclonic whirl which dominates the upper air strata of the higher latitudes wherein there is a general west-to-east air movement.

Figure 5 presents a diagrammatic cross section of the South Polar regions. The curved lines show the course of the isobars at various altitudes. In the vicinity of the South Pole the isobars of the lower layers are arched upward, as is characteristic of an anticyclonic distribution. In the upper layers, above 2,000 m., this arching is absent; in place of it the isobars sag toward the vicinity of the pole in accord with the cyclonic distribution of the "polar whirl." In the district of the anticyclone the air movement is prevailing easterly, but with southerly components; in the district of the cyclone it is westerly, with northerly components.

In figure 5 the arrows show only the meridional components of the winds; in addition the shaded area shows the region of easterly winds. If there were no land masses about the South Pole (the vertically exaggerated profile of figure 5 is quite arbitrary) then we might assume easterly winds would prevail over all the district of the anticyclone. The actual continent, however, permits only a portion of the anticyclone and the easterly winds to appear; and the land rises even into the overlying cyclone and westerly winds.

The boundary between the easterly and the westerly winds (shaded and unshaded portions of the figure) ascends from sea level at latitude 65° S. to meet the land at different latitudes and altitudes, depending upon the local topography. Where the general surface rises rapidly in relatively low latitudes, as at the right of figure 5, there is the least space for the easterly winds to develop; this seems to be the case in East Antarctica and particularly in Wilkes and Victoria Lands. (See figs. 2 and 4.) Where the coast retreats poleward and the back country rises slowly, there the region of the easterly winds is more extensive, as over Ross Sea. Figure 5 shows the supply of moisture to the polar district by poleward-pointing wind arrows; but there is also a vapor supply and condensation at the boundary between westerly and easterly winds in the latter district, as has been explained above. The following observational facts lend support to the scheme presented in figure 5.

The direction of the air currents at the upper cloud layer is seen by inspection of figure 4. In the upper layers the wind follows the isobars, approximately, and in such a manner that in the Southern Hemisphere they have the low center on the right hand. The probable course of the isobars has thus been drawn from the available antarctic observations on clouds and bear these facts in mind. In addition, it has been recognized that Shackleton and Amundsen met with southerly winds on the Antarctic Plateau.

When one studies the upper level isobars and winds, as thus restored, it seems not difficult to explain the sustenance of the inland ice within the nucleus of Antarctica; for it appears that in the sphere of the upper polar whirl there is an inflowing current of air and water vapor. The observations of the upper clouds at the marginal stations justify the conclusion that there is an intake of air at higher levels over the district between Weddell Sea and Wilkes Land, i. e., on the Indo-Atlantic side of the South Polar regions; and perhaps a similar intake over the district east of Ross Sea to the vicinity of the *Belgica* drift journey. Consequently the principal importation of water vapor will take place on this side of the South Polar region. Where the inflowing air strikes against mountain ranges it will be compelled to give up the aqueous vapor it is carrying. The region between Weddell Sea and Wilkes Land is heavily glaciated, as is also King Edward VII Land farther east; perhaps this is the reason for the glaciation. The compensating outflow of the now moisture-poor air seems to take place, on the other hand, chiefly on the west side of Ross Sea and of Weddell Sea. Here the upper winds are frequently from the south or southwest, and the stormy southwest winds of Snow Hill also indicate a lively exportation of air from the Antarctic region.

The very dry air peculiar to the west side of Ross Sea, and which makes itself felt as a characteristic peculiarity of the climate, may then perhaps be explained as the result of this district lying in the lee of Victoria Land and of East Antarctica in general. The westerly currents of the polar whirl, deprived of their moisture by the heights of East Antarctica, attain this district in a desiccated condition which still characterizes them when they leave the south polar regions. The stormy southwest winds of Snow Hill are also extraordinarily dry, yet of such a low temperature as is only to be explained if they descend from some great reservoir of cold, viz, the high-lying central portions of Antarctica.

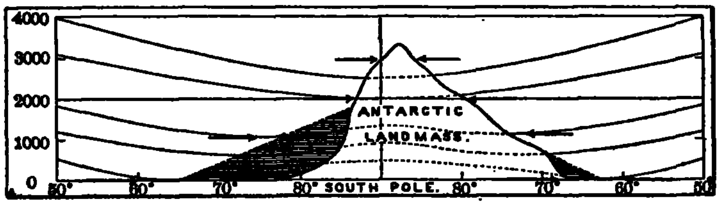

FIG. 5.—Diagrammatic cross section of the south polar regions, to show the position of the isobaric surfaces and the direction of the winds. Arrows show the meridional components of the wind; shaded areas show the region of prevailing easterlies Altitudes in meters.

This concept that the fixed land masses of the south polar regions are of considerable altitude, that they extend up into a suprapolar cyclonic whirl, thus solves in a general way the difficulty of accounting for the ice-covered condition of central Antarctica. It must be the task of future expeditions to secure the detailed foundations for the hypothesis and particularly to reveal the secrets of the upper air over the nucleus of the south polar continent. Far-reaching conclusions will be founded upon this exploration, for in this way it will become possible to secure more intimate knowledge of the processes which promoted the growth of the great inland ice sheets over Canada and Scandinavia in the glacial period. These ancient ice sheets also reached considerable altitudes, and presumably rose above the zone of anticyclonic circulation. It will be in this domain of comparative climatology that future antarctic explorations will yield the most valuable results.

The observation and recording of the marginal movements of the inland ice of Antarctica will be of great importance in judging secular variations in climate. These movements and the magnitude of the ice discharge furnish a very sensitive scale for measuring the secular changes in distribution of precipitation. The great extent of the ice-covered area here smooths out both local differences and transitory anomalies in weather. Only the great and enduring climatic changes, whether periodic or nonperiodic in character, can find any expression in the thickness and velocity of the inland ice. One of the most imperative needs in future antarctic exploration thus seems to be continuous observations of the movements of the inland ice at the largest possible number of stations along its margin.

C. G. S. UNITS IN THE ENGLISH DAILY WEATHER REPORT.

In the MONTHLY WEATHER REVIEW for February, 1914, page 100, Dr. W. N. Shaw mentioned that beginning with the issue for May 1, 1914, the Meteorological Office would extend the use of C. G. S. units of pressure to its Daily Weather Report.

The transition to the new unit is facilitated for the user of the British Daily Weather Report by a table on the first page, which presents the adopted equivalent reduced readings in inches of a mercurial barometer at latitude 45°. Further help is offered on the inside pages by a graphic scale comparing the reduced mercurial barometric readings in inches with the millibars used on the adjacent maps. On the daily charts themselves the isobars are drawn for intervals of 5 millibars, but they are numbered in centibars, and the old-style readings in inches are entered at one end of the line. At first it may cause a slight inconvenience to find the tabulated reports on pages 1 and 4 presenting the pressures in millibars and the 24-hour change in "half-millibars" while the charts use centibars; but no doubt the habitual readers of the Report will soon become familiar with this demonstration of the great convenience of a rational decimal system of notation.

In this connection it is interesting and encouraging to note that simultaneously with the change to Bjerknes's "millibar" comes the change to "millimeter" in the column headed Rainfall. It gives us grounds for hope that eventually the English-speaking races may also adopt a thermometric scale that will combine all the advantages of the Fahrenheit and the centigrade scales.

Recent discussions in the United States make it of special interest to remark here that the continuance of the Beaufort scale of wind force still seems justified in the present improved Daily Weather Report.

In the following paper the Weather Bureau presents its recently adopted standard tables for converting standard barometric readings into millibars.—[C. A., jr.]

[illegible] 11.12

CONVERSION OF BAROMETRIC READINGS INTO STANDARD UNITS OF PRESSURE.

By ROY N. COVERT.

[Dated Instrument Division, Weather Bureau, May 8, 1914.]

Atmospheric pressures may be expressed in several different ways, viz, as heights in inches, or millimeters, of the barometric column of mercury or other suitable liquid; as pounds per square inch or grams per square centimeter of the weight of that column of mercury; or in absolute units of force.

Values expressed in one way are convertible into values expressed in each of the other ways. The conversion of atmospheric pressures, expressed in terms of the linear height of the mercurial column, into the form commonly used in engineering work, i. e., pressures expressed as a weight per unit area, requires a knowledge of the density of the mercury or liquid employed. The equation for this conversion is—

$$P = h\rho, \tag{1}$$

where P=pressure expressed as a weight per unit area,
h=height of the column in linear units,
ρ=density of the liquid, i. e., the mass of a unit volume at a standard temperature.

The conversion of pressure when expressed in linear units of the height of the mercurial column into dynes per square centimeter or millibars requires values for both the density of mercury, ρ, and the acceleration of gravity, g. The equation which gives the pressure in millibars, P_{mb}, corresponding to the barometric height, h, is—

$$P_{mb} = h\frac{\rho g}{1000} \tag{2}$$